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Rationale for granulometric medium characteristics under vibration processing of parts with small grooves and holes

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Introduction. The design technique for a highly efficient technological process of vibration finishing of parts with small grooves and holes is presented. The decision is based on the selection of the granulometric characteristics of the processing environments. The cross-sectional shape and geometrical dimensions of burrs on typical parts of radio electronic equipment (REE) are analyzed. A generalized burr model has been developed. Methodological principles for the selection of particle size characteristics of operating environments are determined.
Materials and Methods. The new classification and coding according to the constructive and technological principles of REE components will provide reasonable selection of the equipment, environments and modes when designing their finishing process.
Results. A technique has been developed for selecting the granulometric characteristics of operating environments with the account of the major technological problems. Based on the design and technological features of the REE components, the dependences are proposed for determining the size and shape of the processing granules. The acceptance criteria for evaluating the results of vibration processing are determined. It is noted that one of the major tasks in the vibration processing of parts with small grooves and holes is to provide such in-process time at which burrs are removed, and the roughness and other surface parameters meet the technical requirements. In this case, the accuracy of the linear dimensions of the processed surfaces should be considered an indicator of quality. Quantitatively, this criterion is assessed on a specific index whose calculation considers the largest actual size before vibration processing, the burr height, the smallest allowable size after processing, and the tolerance established by the technical requirements. The process efficiency criterion is defined as the ratio of the machinability index to the processing time of a batch of parts or the cycle time per part. The proposed criterion enables to compare treatment processes under validating the solution to technological problems.
Discussion and Conclusions. The study results enable to confirm that vibration processing in the organic environment contributes to the effective removal of burrs and edge smoothing of small-sized parts of electronic equipment with small grooves and holes.

Keywords: vibration treatment, roughness, surface pattern, burrs, edge smoothing.

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Introduction. The recently increased demand for precision machining of parts is particularly topical in the machine and instrument industry, since in these industries, the annual volume of manufactured parts exceeds hundreds of thousands of pieces. It should be emphasized that the details of radio-electronic equipment (REE) have a rather complex configuration of the outer contour. Most of them are characterized by such non-technological elements as grooves and

small holes, deep holes, blind threaded holes, etc. Finishing of such parts in granular media has proved its effectiveness [1, 2]. Currently, there are no methods for designing finishing and clearing operations for such parts, which limits the wide-spread introduction and further improvement of vibration processing.

Materials and Methods. Based on the design-engineering analysis of REE parts manufactured at the instrument-making plant, classification was developed and their coding was performed according to the design-engineering principles. The new classifier will provide selecting equipment, environments and operation modes at the design stage of the part finishing process with account for their design-engineering features.

Finishing and clearing processing plays a special role in providing the quality of REE parts, which is difficult to perform under modern production conditions due to the complex structural shape of products.

One of the major methods of forming blanks in mechanical engineering and instrument making is edge cutting machining. However, any mechanical processing based on cutting results in defects such as burrs, sharp edges, etc. They occur due to the laws of continuum mechanics, so these disadvantages cannot be excluded even when using modern processing centers and optimum processing modes. As a result, functional, aesthetic, and ergonomic problems may occur during the manufacture and operation of parts [3, 4]. This proves urgency of the problem of deburring under finishing and clearing operations of REE parts.

The research work objective is to improve the methodology for designing highly efficient vibration treatment of parts with small grooves and holes based on the selection of granulometric characteristics of flexible working environments.

To achieve this goal, it is necessary to solve the following tasks:

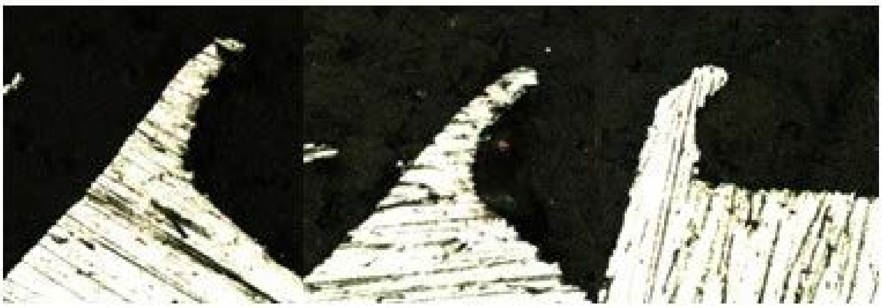
— to analyze cross-section shapes and geometric characteristics of burrs on typical parts of devices,

— to develop a generalized burr model,

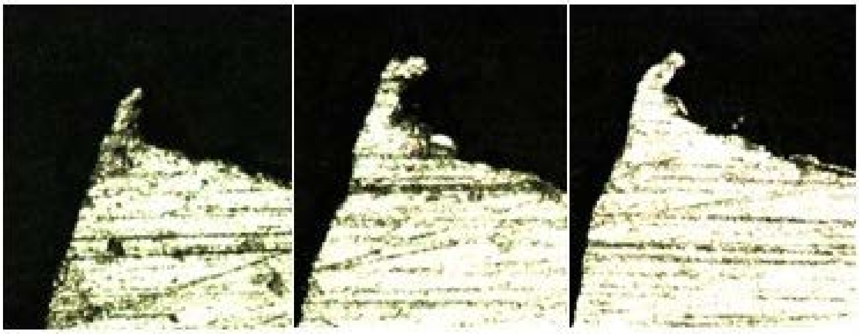
— to justify methodological approaches when choosing granulometric characteristics of processing environments.

To study the geometry and parameters of the cross-section profile of burrs, micro-sections were examined using a metallographic inverted microscope equipped with the Thixomet Pro system. As the study has shown, the main shape of the burr cross section is a triangle. At the same time, the height of the burr is on average 2-3 times greater than the thickness of its base, and the linear thickness sizes do not exceed 0.4 mm (Fig. 1).

a)



b)



c)

Fig. 1. Cross section of burrs in the studied samples. Sample material: *a*) BrOC4-3; *b*) LS-59-1; *c*) AMg6

In this case, the choice of characteristics of the processing environment has a decisive influence on the surface quality of parts and process performance [5–7]. At enterprises, they use working media whose granules can be classified according to their geometric shape and size, material, and size of cutting grains, as well as material of a bundle of grains, structure and the production method.

For ease of designing finishing and clearing vibration treatment, a system classification and coding of granules of working media is proposed.

Finishing and clearing of REE parts provides for deburring and surface preparation for coatings. In instrument engineering, various coatings are used: galvanizing, cadmium-plating, nickelizing, chrome-plating, brassing, palladizing, silvering, gold plating, passivation, etc. To the surface patches of the electrocontact parts of devices, electrolytic coatings (silver, gold) are applied. They are characterized by high electrical and thermal conductivity and chemical resistance under the increased humidity conditions [8, 9]. Electroplating requires a certain quality of the workpiece. No burrs or sharp edges are allowed.

As the analysis of structures under finishing and clearing REE parts has shown, environments that meet the following requirements should be used:

— high density (at least 1.2 g/cm^2) with a low weight of the granule;

— suitable for processing non-rigid workpieces;

— suitable for processing workpieces with angled surfaces and areas with limited access to the granule of the processing environment;

— high wear resistance and ability to keep its shape during processing;

— uniform structure of the granules.

Taking into account these requirements and the data of the works [10, 11], it should be recognized that the use of stone granular media are most appropriate. When crushing the fruit pips and walnut shells, freeform granules with V-shaped edges are formed. Thanks to this, the granule becomes an analog of a cutting tool. In this case, different areas of the part are available for microcutting.

Research Results. So, environments made of natural materials are optimal for finishing and clearing REE parts with small grooves and holes. The widespread use of this approach is hindered by insufficient knowledge of such environments and the unavailability of methods for designing finishing and clearing operations using them.

As a rule, under finishing and clearing vibration processing of REE parts, three technological tasks arise.

First. If it is sufficient to remove the burrs and smooth the edges on the workpieces, there is no need to process the internal surfaces of the grooves and holes. This is the most typical task that is solved under processing parts. In general, it can be solved through applying granules with size $R_{\text{гр}}$, greater than the size of the largest hole or groove L, i.e., $R_{\text{гр}} > L$. This will eliminate jamming in them.

The processing environment contact will be considered as the contact of a single granule until the burr is completely removed and the required amount of edge smoothing is obtained (Fig. 2).

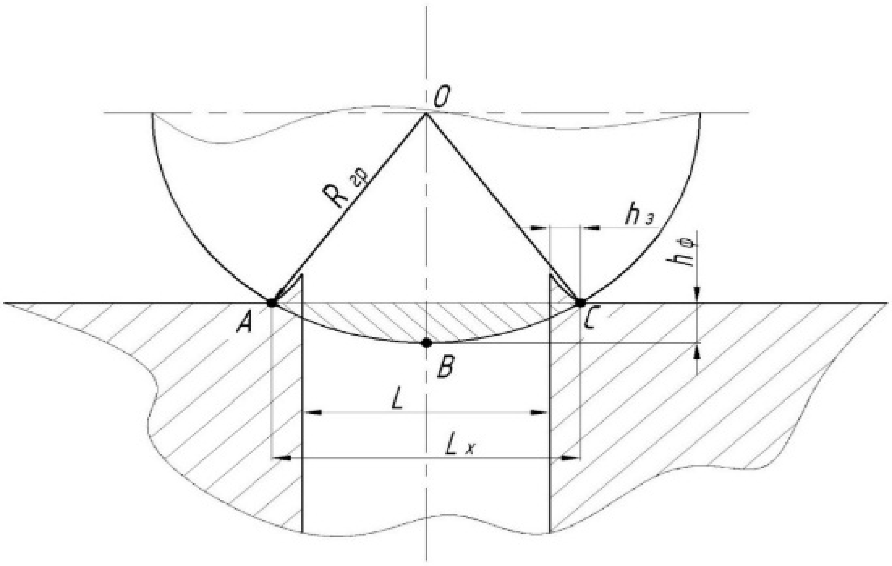


Fig. 2. Geometric layout of granule contact with hole edges

We take into account the wear coefficient of the granule K_u, which largely determines the consumption of the processing environment, as well as the process performance and the quality of the surfaces. The optimal radius of the working medium granule is determined by the expression:

$$R_{\text{гр}} = K_{\text{и}} \frac{(L+2h_{\text{з}})^2 + h_{\text{ф}}^2}{8h_{\text{ф}}},$$

where $h_{\text{з}}$ — thickness of the base of the formed burr, mm; $h_{\text{ф}}$ — chamfer size that meets the technical requirements, mm; L — linear or diametric value of the processed element, mm.

Compliance with this condition guarantees the burr removal on the outer surfaces and providing the radius of smoothing edges required by the drawing.

Second. This problem occurs when it is necessary to process and prepare for coating the internal surfaces of grooves or holes. In this case, the criterion for selecting the particle size should be the size of the smallest hole or groove L_{min} of the part.

To avoid jamming of the working environment particles in the holes and grooves, it is recommended to select their size from the ratio:

$$D_{\text{гр}} = 0.6 \div 0.7 L_{min},$$

where $D_{\text{гр}}$ — effective diameter of the processing environment granules, mm.

However, when selecting the size of the working environment particles using this ratio, it is critically important to analyze its applicability for processing other holes and grooves of the part that are larger than L_{min}. If their size is equal to $2D_{\text{гр}}$ or $3D_{\text{гр}}$, it is possible to jam the particles of the working environment, which will interrupt processing the surface of the hole or groove. To prevent this phenomenon, the dimensions of the holes and grooves to be processed L should be within the range $L_{min} < L < 1.7D_{\text{гр}}$, $2.2D_{\text{гр}} < L < 2.7D_{\text{гр}}$, $L > 3.2D_{\text{гр}}$ (Fig. 3).

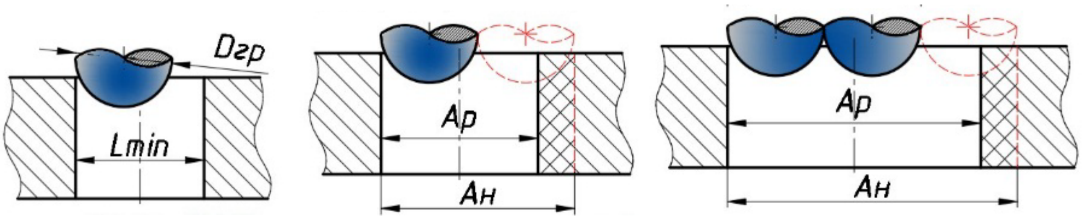


Fig. 3. Dimensions of holes that prevent jamming of the working environment bodies:
Ar — recommended size, An — unacceptable size

Third. The primary process task is treatment of the interface points of surfaces. Its solution causes the greatest difficulties, since it is hard for granules to reach surfaces that are at an angle to each other. One example is thread. If the technical requirements of the part specify the radius of the interface of the surfaces, the size of the granule of the working environment must be equal to it or less:

$$R_{\text{гр}} \leq r.$$

As shown in [12–14], due to violation of this condition, three conditional zones can be formed during vibration treatment of angled surfaces:

— a dead zone (no processing occurs in it)

—- an open zone,

— an unstable roughness zone (Fig. 4).

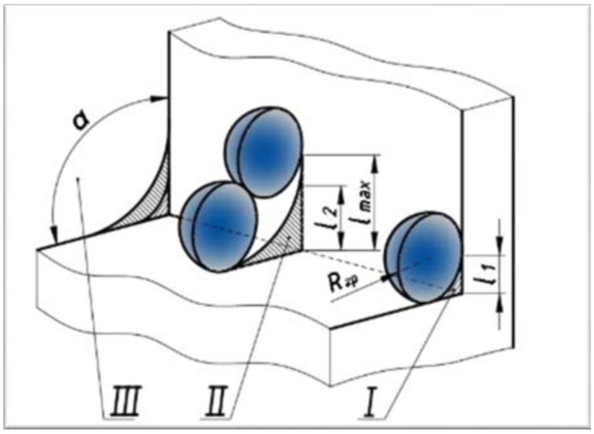


Fig. 4. Untreated areas that occur with the wrong selection of granule sizes

The dimensions of the dead zone and the zone with unstable roughness can be calculated from the formulas:

$$CD \leq R_{\text{гр}}\left[\frac{1}{\cos\frac{180^0-\alpha}{2}} - 1\right];$$

$$CB = R_{\text{гр}} \tan\frac{180^0-\alpha}{2}.$$

For processing hard-to-reach surfaces with organic V-shaped particles, we can introduce the concept of the granule permeability coefficient, which is determined from the ratio of the mating angle of the surfaces to the angle of the V-shaped edge forming the cutting edge:

$$K_{\text{пр}} > \frac{\alpha}{\beta}.$$

Considering the permeability coefficient when selecting the shape of granules will solve a complicated process task associated with finishing treatment of surface interfaces.

To control the finishing and clearing result, it is required to formulate criteria for the validity of parts or their batches. For REE parts, these criteria will be the surface roughness parameters and the stability of the quality characteristics of the treated surface (Fig. 5).

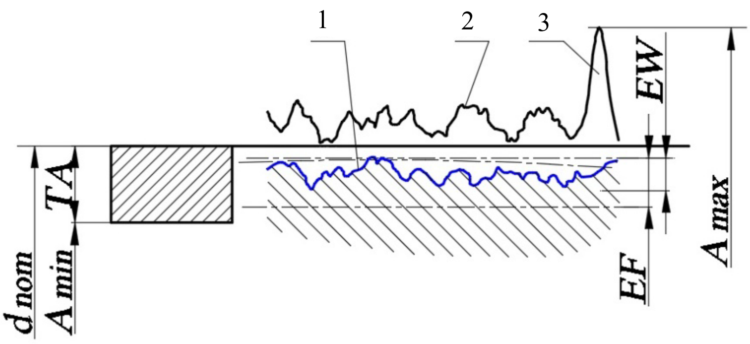


Fig. 5. Scheme for determining the processibillity index: 1 — surface roughness after processing; 2 — actual surface roughness; 3 — burr; *EW* — waviness deviation; *EF* — shape deviation; A_{max} — the largest size before processing with account for the burr height; A_{min} — minimum size after processing; TA — tolerance for the processed size

The main condition for solving this process problem:

$$\overline{R_i} - \delta > [R_{imin}],$$

where $\overline{R_i}$ — the average statistical reading of the data values taken by the indicators, which correspond to the arithmetic mean deviation of the reference surface contour; δ — the scattering field of the values of qualitative indicators, which cor-

respond to the values of metal removal rates under processing; $[R_{imin}]$ — the value of the quality indicators within tolerance.

Quality indicators within a batch of parts will be random variables distributed according to probabilistic laws. Therefore, the criteria for batch validity (i.e., the optimality of the proposed technology) can be set by the inequality proposed above. At the same time, you need to take into account the defective ratio that does not exceed the probability Pi [15]:

$$P_i(|R_{ij} - \bar{R}_i| \geq \delta) < \frac{D_i}{\delta^2},$$

where P_i — the probability of *i*-th quality indicator falling outside the boundaries of the scattering field; D_i — the calculated value of variance R_i.

One of the main tasks under the vibration treatment of parts with small grooves and holes is to provide such process duration at which burrs are removed, and the roughness and other surface parameters meet the technical requirements. The quality indicator is the accuracy of the linear dimensions of the processed surfaces. This criterion is quantified by the processibillity index (Fig. 5):

$$C_{\text{o}} = \frac{A_{max} - A_{min}}{\text{TA}},$$

where A_{max} — the largest valid size before vibration processing with account for the burr height; A_{min} — minimum permissible dimension after treatment; TA — work dimensional tolerance set by technical requirements (Fig. 5).

The criterion of process efficiency is defined as the ratio of the processibillity index to the duration of the processing of batch of parts, or cycle time reduced to one part:

$$K_{\text{э}} = \frac{C_o}{t_{\text{ц}}}.$$

The proposed criterion provides comparing treatment processes when justifying the solution to the problems.

Discussion and Conclusions. The paper analyzes the cross-section shape and geometric dimensions of burrs of typical parts of REE devices. A generalized burr model has been created, and methodological principles for selecting the characteristics of granules of working environments have been proposed.

Methods for selecting granulometric characteristics of processing media depending on the main process tasks are described. Dependences are obtained for determining the size and shape of processing granules based on the design and technological features of REE parts. The validity criteria for evaluating the vibration treatment results are proposed.

The study results suggest that finishing and clearing vibration treatment in an environment of crushed pips contributes to the effective removal of liquids, including burrs, as well as the edge smoothing in the radio-electronic equipment parts of complex configuration.

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Claimed contributorship

M. A. Tamarkin: academic advising; analysis of the research results; correction of the conclusions. E. N. Kolganova: basic concept formulation; research objectives and tasks setting; text preparation; formulation of conclusions. M. A. Yagmurov: computational analysis; the text revision.

All authors have read and approved the final manuscript.